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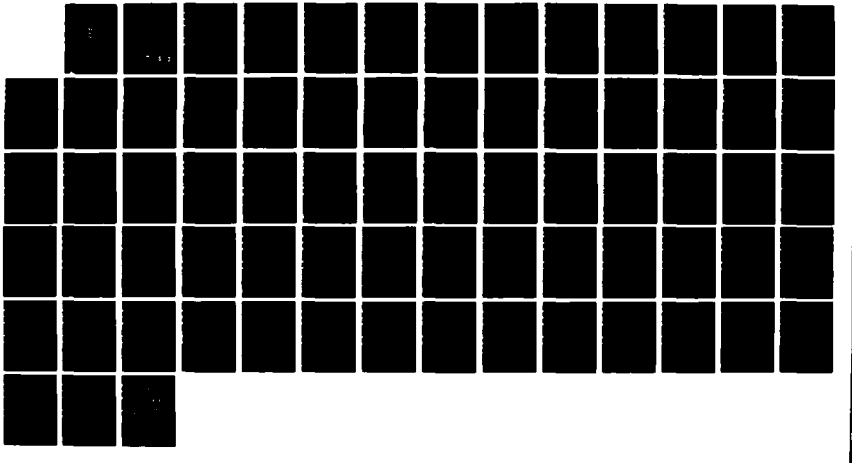

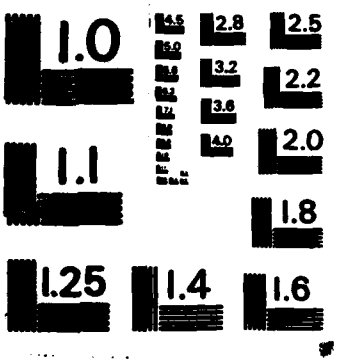

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BEHAVIORAL CONSIDERATIONS FOR SPACE STATION DESIGN

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AND

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JANUARY 1986

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Thomas E McCann

THOMAS E. McCANN, Lt Col, USAF
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Flight crews are more than just the sum of the members' individual technical skills. They are dynamic and constantly changing systems of interacting units. The critical factor in this system is the interaction process. Factors which affect this interaction process are design considerations critical to the successful operation of the human system in space. Future space missions will be longer and will involve more routine tasks. Crews will be larger and more heterogeneous. These conditions make proper consideration of group dynamics principles imperative. Formal design of future space missions, should consider critical design factors which promote the group process. The real change to current NASA mission design suggested by this report is that greater consideration be given to the informal processes characteristic of the human system. Consideration of these factors will pay large dividends in terms of human system performance and neglect of these factors will incur costs. keywords:

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-ABSTRACT-

BEHAVIORAL CONSIDERATIONS FOR SPACE STATION DESIGN

Flight crews are more than just the sum of the member's individual technical skills. They are dynamic and constantly changing systems of interacting units. The critical factor in this system is the interaction process. When this process is effective, the output of the system can be more than planned. When this process is faulty, experience shows the output is likely to be much less. Factors which affect this interaction process are design considerations critical to the successful operation of the human system in space.

Future space missions will be longer and will involve more routine tasks. Crews will be larger and more heterogeneous. These conditions make proper consideration of group dynamics principles imperative.

In the formal "top-down" design of future space missions, NASA, where possible, should consider critical design factors which promote or impede the group process. Specifically:

1. Task specification should facilitate interaction by requiring mutual support and cooperation.
2. Roles should be specified but allow some adjustment for individual or situational differences.
3. Lines of authority should be clearly established but realistic in regard to changing mission requirements.
4. Crew facilities should be designed to promote crew interaction without "crowding" individuals.

5. Selection should consider compatibility as well as technical expertise.

The real change to current NASA mission design procedures suggested by this report is that greater consideration be given to the informal "bottom-up" processes characteristic of the human system. That is, consideration should be given to how the crew respecifies roles, builds compatibility, promotes cohesion, and improves productivity. In short, consideration must be given to factors which promote informal "bottom-up" support of the formal "top-down" design.

Perhaps the most effective way to influence the "bottom-up" development process is through crew selection and training. In this regard:

1. Selection of whole crews (rather than individuals) should be based on compatibility and performance.
2. Crews should be trained as a group, not as individuals. Over time, interaction problems will be identified.
3. Crew training should include training in effective interaction and group dynamics. This will allow the human system to "heal" itself should problems arise in space.

Consideration of these factors will pay large dividends in terms of human system performance, and neglect of these factors will incur costs. Actual changes to NASA policies and current practices may be minimal but nevertheless critical.

BEHAVIORAL CONSIDERATIONS FOR SPACE STATION DESIGN

Lt Col Frank R. Wood and Captain Karen O. Dunivin

The Problem

The nature of the mission in space has changed. Previous missions have involved small crews, persons with similar backgrounds and experiences (DOD), missions of short duration (generally less than 7 days), and tasks primarily designed to prove that man can survive and perform effectively in space. Missions now being proposed will involve larger crews (up to 16 people), longer missions (60-90 days), working groups with different backgrounds (sex, education, expertise, nationality, orientation, etc.), and will require performance of multiple tasks including space station maintenance operations, mission specific operations (specialized experiments), and extra-vehicular activity. While the nature of the mission has qualitatively and quantitatively changed, the environment in which it is conducted is basically the same. Therefore, these proposed changes will affect the human sub-system perhaps more than any other system in the total mission environment.

Previous literature has tended to neglect the importance of the human sub-system. Its primary emphasis has been on the question of whether man can survive and perform critical tasks in space; thus, focusing on technological and physiological aspects of the mission. The assumption implicit in literature with this emphasis is that crews are highly motivated, mature, cohesive and efficient. In support of this view, the Martin Marietta

spaceflight simulation (cited in The George Washington University Medical Center Report [GWUMC], 1974) states that the success of a mission can be explained in terms of the crew being professional aviators interested in the technical problems of space. The report concluded that the greater the training and preparation for the flight, the less the chance for flight difficulties. In a similar vein, Christensen's review of a MARS trip (cited in GWUMC, 1974) advises that rehearsal of highly skilled tasks should occur on at least a daily basis. Indeed, even the selection and training process has emphasized technical and task qualifications and neglected social skills. For instance, the NASA report (1975) on the Apollo missions describes crew selection and training based exclusively on technical requirements, and there is no mention of the need for social skills or understanding group dynamics. The NASA report (1977) on the Skylab missions lists four objectives of the program, none of which deal with social skills, group dynamics, or interpersonal relationships in isolation over extended periods of time.

This trend is also evident in the Russian space program literature. The 1979 annual summary of USSR "Space Life Sciences Digest" has only one page on crew selection and training and this limited material emphasizes technical aspects. There is no mention of human relations skills or group dynamics training. Zaitsev (1982) carries the emphasis on technical aspects to its logical extreme by suggesting the automation of space missions with the use of robots instead of man. Bluth's review (1982) of previous studies on isolated environments counters the functional

emphasis in these studies by reporting that the Soviets initially screen subjects based upon physical and psychological qualifications. For example, in the Salyut 6 mission, each crew member was pretested and trained for compatibility and group interpersonal skills. Along with technical training, the crews were also trained on conflict and stress resolution with the use of role playing. After each exercise, they and the team behavioral scientist reviewed their social interaction techniques for effectiveness. In fact, the behavioral scientist was considered an integral part of the team and a colleague of the crew.

The Human Sub-System

The human sub-system can no longer be neglected. Like any system, it must be properly designed to accomplish its goals efficiently. Unlike the other sub-systems, the human sub-system has greater flexibility to adapt to the changing demands of the tasks and environment. Therefore, it can be designed to master rather than to adapt to the environment, to creatively solve problems, and to produce more than originally intended. This ability to change poses both a promise and a threat. While the system is flexible, it is also unpredictable. Since change is an inherent characteristic of the human sub-system, the dynamics of change in this system must be understood for the system to be properly utilized.

The human sub-system can be formally designed before flight to accomplish specific purposes - a 'top-down' design process. That is, the organization (NASA) can specify goals, roles to support those goals, norms to support the roles, and individual

behaviors which will support those norms. In this manner, the interaction of crew members can be designed to accomplish specific tasks, authority structures specified, and relationships between positions can be predetermined. Further, since no consideration is made for individual differences in this design process, crew composition can be determined by technical skills and qualifications, not by personal compatibility or social skills.

The 'top-down' design process is important because it specifies the structure of the human sub-system and establishes a stable framework within which the interaction of crew members can occur. However, in the absence of established patterns of relationships or if the situational changes demand a new structure, groups will develop their own structure following a 'bottom-up' design process. In this process, individuals through their behavior, will specify their own group norms, their own roles, and their own goals for the system. This "bottom-up" design process is an on-going process in all groups. All groups, even those that appear relatively stable in their overall structure, face strains, tensions and threats to whatever equilibrium they have been able to establish.

The 'top-down' formal design process is characteristic of NASA's orientation with regard to the crews assigned to the early missions and represents a reasonable first step in organizing groups to operate in unknown environments. However, missions are becoming more complex, and roles are becoming more specialized. Bluth (1979) reports that roles are becoming more specialized and formalized as evidenced by the functional distinctions between

astronauts, mission specialists, payload specialists, and principal investigators. In addition, crews are becoming larger, more heterogeneous, and tasks are becoming more complex.

All of these factors affect the dynamics of the human sub-system. Numerous studies suggest that the probability of group dysfunction increases as the length of time in isolation increases. These studies include: 1965 USN Air Engineering Center space simulation - 34 days; 1959 USN Air Material Center space simulation - 8 days; 1973 Skylab I mission - 28 days; and 1964-1965 Sealab I and II underwater missions - 11 and 15 days (cited in GWUMC, 1974). Rawl's review (cited in GWUMC, 1974) of interpersonal climate concludes that as length of time in isolation increases, group cohesiveness decreases, then shows a sharp increase towards the end of the mission. Bluth (1982) who reviewed other isolation environments, concludes that two to three-week missions do not show social problems, but anything longer generates interpersonal problems. Whether the human sub-system survives or dissolves under such pressures may depend upon the consideration given to the design characteristics critical to its operation in future mission planning.

Analysis of the human sub-system in terms of the 'top-down' design of group structure and the 'bottom-up' informal organizational process provides a meaningful framework to understand how crews operate in space and why they sometimes fail to meet expectations set for them. Cooper (1976) warns that the neglect of these design considerations in the past explains the reduced productivity experienced during past space missions. For example, during Skylab III, poor relationships between flight

crew and mission control caused the flight crew to announce to mission control one day during the sixth week that they were "taking the day off." Only later when the flight and ground crews talked and cleared the air, did the flight crew's performance improve.

Groups change over time and informal structures emerge. Therefore, group design must allow for these changes in structure and patterns of the organization. Bluth (1979) advises that the fit between task, organization, and people must be optimized, but cautions that the pattern of the organization is contingent on the nature of the work and the particular needs of people involved. Therefore, the informal organizational structure must be allowed to operate.

Past experiences in analogue environments would have predicted dysfunctional outcomes such as those noted in Skylab III. Therefore, a design of the human sub-system in future space missions should employ known principles of group dynamics and past experiences in analogue environments to identify design considerations critical to crew performance.

Design Considerations

The literature identifies several critical design considerations crucial to the efficient operation of the human sub-system including: specification of roles; design of authority systems; composition and compatibility of crews; task characteristics; impact of the environment and facility; and crew selection and training. All of these factors are suggested by group dynamics theory and research which, at first glance may not seem appropriate because of the laboratory and field situations

in which the data were gathered. These situations, however, are appropriate for the study of the behavioral phenomena themselves, and replication across various situations has shown these principles to be valid explanations of group behavior in general. To demonstrate the applicability and importance of each of these design considerations to the NASA space mission scenario, each discussion of a particular design consideration will include both a theoretical treatment of the group dynamics principles involved and reports of their impact in analogue situations. This approach will provide both an understanding of the phenomena and an appreciation for their importance to NASA space mission planning.

1. Role Specification

The activities of groups are organized both formally and informally by the specification of roles and norms of behavior which support those roles. This specification has typically been formally accomplished by NASA through the design of checklists and time schedules specifying what needs to be done, when, and by whom.

In all groups an informal process of role specification also operates simultaneously. This informal process may either support or conflict with the specifications formally imposed from outside. That is, each group respecifies its roles and norms of behavior through interaction. Essentially, the group redefines what is "really" expected of each group member. The dynamics of this informal specification process explain how groups organize themselves, and why some are more effective than others in accomplishing their assigned tasks.

Norms are an essential component of role specification. They are shared expectations about behavior under given circumstances (Homans, 1950). They are prescriptions about what group members are expected or allowed to do as well as what they are not allowed to do. Essentially, they are sets of rules for behavior, some of which are formally determined by the organization and others which are informally determined by the group, itself. According to Dubin (1958), Dalton (1959), and others, informal norms are inevitable in organizations because no set of administratively derived rules can be complete enough to cover all the situations or problems confronted by the group. Further, Crosbie (1975) suggests when official rules are excessively demanding or when they threaten the group structures or solidarity, the group will substitute its own norms.

Norms are important to roles because they become the basis for the social control of group members. Social control is the process by which group members pressure individuals to conform to the norms or standards of behavior which are accepted by the group. When the individual's behavior is in accord with the norms of the group, the individual receives the group's approval. However, if the group finds that the behavior of the individual deviates from the group norms, the individual has four choices: to conform, to change the norms, to remain deviant, or to leave the group.

The literature suggests that the pressure for conformity can be very intense, especially when both formal and informal pressures are applied. For example, the classic studies by Asch (1951, 1952, 1955) and Sherif (1935, 1936, 1961) demonstrate that

knowledge of a majority opinion, an informal norm, is enough to lead some individuals to conform publicly to a judgment which differs significantly from the one they privately hold, and that group norms persist even when the individual is alone in later situations. The power of formal norms is vividly illustrated in the classic obedience experiments of Milgram (1963). In general, the literature shows that individuals are more likely to conform under the following conditions: when the situation is ambiguous, when the deviant act is highly visible, when the majority supporting the norm is large, and when the group is especially close-knit (Hare, 1976).

When norms refer to the expectations for a single individual or a particular position within the group, they constitute a social role -- a cluster of expectations for the behavior of any individual who occupies that role. Roles accomplished in groups may be both formal and informal. Examples of formal roles include astronaut, principal investigator, payload specialist and mission specialist. Informal roles may include joker, critic, worker, supporter, conformist, leader, or simply member (Cloyd, 1964; Couch, 1960). In general, roles accomplished in groups tend to be oriented toward both task and social-emotional areas (Bales, 1958; Bales & Slater, 1955).

In some cases roles are a source of trouble for the individual, especially when the roles are by nature ambiguous or make demands which are incompatible with other roles. Role ambiguity occurs when persons are unsure of the behaviors required of them. For example, when an individual arrives as a new member of a group, or when a group is faced with a new task,

role expectations are unclear. Role conflict occurs when incompatible behaviors are required of a person. For example, when a new member arrives with certain roles intact (especially those associated with age, sex and race) or an expertise which is not valued by the group, the person is faced with the conflict of which behaviors are appropriate. Both of these role problems operate to reduce the efficiency of any group, and may be corrected by proper role specification.

The importance of clear role specification is evident in the problems experienced during the Antarctic Deep Freeze (1955-1968) studies and the 1977 Spacelab Mission Development (SMD III) Tests. The 1966 Antarctic study showed that new arrivals were less effective in accomplishing their tasks because they were unsure of the group goals. The SMD III test showed overall crew effectiveness was reduced by role overlap and subsequent conflict between payload specialists and mission specialists who were trained differently. In general, role specification is easier in situations in which tasks are highly structured and predictable, the crews are homogeneous and small in number, and training of the entire crew is accomplished together.

In summary, NASA can expect their space station crews to develop informal roles and informal norms, and these roles and norms are likely to have powerful affects on group and individual behavior. This development is normal in the bottom-up design process. Should some minority of the crew become disenchanted with other group members, the mission, or the habitat and engage in dysfunctional behavior, one can expect the majority to exert considerable and effective pressures for conformity because the

deviant act will be highly visible (the ever-present Mission Control), and the majority will remain close knit and exhibit a unified opinion. It is unlikely that a majority of an astronaut group will develop counter productive roles and norms, so this aspect of group dynamics should serve the needs of NASA in most cases.

One possible exception deals with crew rotations. If partial crew rotations are attempted to ensure mission continuity, the newly arrived people must ease into the established social context. They will not be privy to how and why the informal norms and roles developed; how the existing crew has chosen to cope with the rigors of the space station environment. Groups that have worked out the delicate balance of task accomplishment and group maintenance under trying conditions resent any threat to that balance. Therefore, at least initially, new crew members should accept the informal norms and gravitate to the informal roles (comic, facilitator, technical expert) that keep the group functioning.

2. Authority Systems

Another important design consideration is the structure of the authority systems. Authority can be based upon the position in the organization or on the person who holds that position. French and Raven (1959) list five sources of power: legitimate, reward, coercive, referent, and expert. Authority based upon a position relies on legitimate, reward and coercive power. Weber's classical view of authority (1947) supports the traditional positional-based authority. This view holds that authority originates at some higher level (God, king,

bureaucracy), and then is lawfully passed down from level to level. For example, military leaders have a right to give lawful orders, and subordinates have an obligation to obey. Positional-based authority is traditional in the military as evidenced by the command system with the different rank structure. Many previous space missions were composed of military men who supported this classical view of authority which recognizes legitimate, reward and coercive power. Even so, evidence provided by the Sealab experiments (1964-1965) demonstrates that clear-cut lines of authority based on positions must be established prior to any venture in order to prevent devisive power tactics or deviations from mission activities.

An authority structure based on personal power derives its authority from the expert and referent power of an individual (French & Raven, 1959). It is more characteristically found in a research project team where the most knowledgeable and, perhaps, the most respected person has the overall responsibility of an activity. In this case, expertise rather than rank determines who has authority.

Many large, complex organizations use a matrix organizational structure with dual authority by both the functional command (position power) and project team command (personal power). For example, in the aerospace industry, a new aircraft development project is usually put under the functional command of the production division, but often is also run by the project team director who is the expert.

Regardless of the source of power, it is important that the authority be accepted by the group or individual, otherwise

conflicting norms or deviant behavior may result. This acceptance view suggests that the basis of authority lies with the influencee rather than in the influencer (Weber, 1947). In other words, those who are being influenced allow the influence only to the degree to which they view the personal or position power of the leader as legitimate.

In future space programs such as a space station with mixed military and civilian crew composition, the authority structure should be designed according to the situation and tasks. Bluth (1979) recognized the need for a matrix organization and multiple command system by concluding that there should be specific roles and a clear authority structure within any given project or experiment in order to reduce role conflict. And, considering the 1977 SMD III study, she suggested that lines of authority within a project should reflect the demands of the mission rather than the position of the individual in the larger organization. This view supports the matrix organizational structure with dual authority.

Within any authority structure, leadership is an important function, and the effectiveness of leaders or leadership style varies depending on the situation. Shaw (1981) contends that a person with task-related abilities and skills (task expertise) more easily obtains a position of leadership which encompasses legitimate power. The most effective leader has both expert and legitimate power. Shaw (1981) also asserts that the source of a leader's authority influences both the leader's behavior and the reactions of other group members. Effective leaders are characterized by task-related abilities, social ability, and

motivation to be a leader. They are technically competent, have the interpersonal skills to deal with group conflict, and they exhibit a desire to be the leader. The U.S. Navy Tektite study (1969-1970) concluded that research teams where the scientist-aquanaut (mission expert) functioned as the leader, the teams accomplished more tasks than those with engineer (position) leaders (cited in GWUMC, 1974). Bluth (1979) noted that the lines of authority within a project should reflect the demands of the mission rather than the position of the individual in the larger organization. Haythorn, in his review of the composition of groups, concluded that crew morale is lowered when leadership roles are limited to a few crew positions (cited in GWUMC, 1974).

Two critical aspects of the leadership situation are the environment and tasks. As they change, leadership styles and the basis of authority must also change. Shaw (1981) hypothesizes that the kind of leadership abilities required for effective group action changes with the type of tasks. He cites Fiedler's Contingency Model (1964) where task-oriented leaders perform more effectively in very favorable or unfavorable situations. Conversely, relationship-oriented leaders perform more effectively in moderately favorable situations. The situation is defined by how good the leader/member relations are; how structured the task is; and how much position power the leader has. If we assume that future space missions will have good leader/member relations, highly structured tasks, and the designated commander has high position power, the task-oriented leader will be more effective. However, if any variable changes (for example, the task becomes less structured, interpersonal

conflict occurs or rank becomes less important), the situation will become moderately favorable and the relationship-oriented leader will be more effective. In the 1965 Sealab III experiment, the crewmen were asked to describe the ideal leader for underwater experiments (cited in GWUMC, 1974). They pictured an older, mature, perhaps aloof, task-oriented man rather than someone more social, which fits the picture of Fiedler's task-motivated leader.

Fiedler and Meuwese (1963) suggest that groups operating with a lot of external environmental stress (threat) may require a therapeutic leader to decrease member anxiety to facilitate crew member concentration on assigned tasks. In intermediate conditions of stress, however, a more permissive, less structured style of leadership is best. As space missions become less threatening (we have proven man can survive and perform essential tasks in space), stress is reduced and less directive, less structured leaders may be more effective. Levine's review (cited in GWUMC, 1974) of prolonged isolation concludes that capable leadership can prevent stress from reaching the danger zone, which supports Fiedler and Muewese's findings. Design of a group's authority structure then must carefully consider tasks and environmental constraints to insure that the appropriate authority structures and leadership styles are employed, otherwise group dysfunction may result.

Based upon the public record, NASA has selected mission commanders using criteria such as military rank, length of experience with NASA, previous space experience, amount of flying experience, and level of technical skills. Presumably, NASA

administrators also used criteria such as the esteem with which these men were held by the organization and the respect they had earned from their fellow astronauts. Most likely past mission commanders, serving as team leaders, held both position power and personal power. While the accuracy of this supposition is not well documented by the public record, effective leadership in past space missions has not been an issue.

Several reasons for the relative unimportance to date of leadership issues in space may be hypothesized. First, all crew members have been so well trained, so highly motivated, and so task-specialized and essential that leadership has not been required to obtain maximum productivity. Second, mission activities and schedules have been programmed so meticulously long before the mission, and monitored by a large contingent of ground support personnel during the mission, that the mission commander has little latitude on how he will marshal and supervise his human resources. In fact, Mission Control may be the actual command authority. Even if schedules get disrupted, Mission Control oversees the development of new schedules. The tether to Earth is fairly tight. Third, with the exception of the later Skylab missions, U.S. space activity has been of fairly short duration. Rarely can the effectiveness of leadership be determined in such a short time.

Mixed and probably less dedicated crews performing routine functions for longer periods of time will provide a greater test of leadership. With some pre-mission knowledge that behavioral problems may occur, the positional leader (with a background of successful command or training) should succeed. One trap for the

positional leader, however, is dealing with a task expert or principal investigator who is on the mission to conduct a critical scientific experiment. As the recognized expert, this scientist will derive personal power and some legitimate authority as a leader, at least in a limited realm. If the roles and responsibilities are not worked out prior to the mission (the matrix organization), conflicts on task priorities, what is the primary mission of the space station, and who makes the final decisions are likely to result.

3. Crew Composition and Compatibility

Crew compostion is the basic component of crew compatibility, and crew compatibility affects crew members' performance of their specified roles. In general, crew composition is defined in terms of heterogeneity and homogeneity of crew member characteristics. While this may provide the basis for crew compatibility, other factors such as group size, circumstances under which crew members interact, and the amount of time they are together may be just as important.

a. Personal Characteristics Affecting Compatibility

The relationship between crew composition and compatibility is complex. Most researchers reduce this relationship to the most basic issue of "attraction"; that is, how attracted are the members of the group to each other. Attraction is a question of "interpersonal choice" and is best examined through sociometric diagrams of friendship groups. In general, interpersonal choice in friendship groups is a function of several factors: proximity, which determines interaction opportunities; similar biological traits, which is an aspect of physical attraction; similar or

compatible personality characteristics, which promote interaction over longer periods of time; shared or complementary roles based on age, sex, and group position, which facilitate long-term interaction; and common interests or values which tend to generate similar attitudes and behaviors (Hare, 1976). Thus, in friendship groups, factors promoting similarity are important predictors of attraction.

Not all groups are friendship groups; some are formed to accomplish tasks, and choices within these groups may be based on different criteria. Task-oriented groups are the most common type in a work situation. In task-oriented groups, reciprocal need fulfillment becomes important; that is, people are attracted to others who provide them with rewards they desire. Indeed, this is the major difference between primary groups which are formed to provide valued relationships and secondary or task groups which are formed to accomplish tasks. An individual's attraction to the members of either group may well depend on the individual's own values. In general, subjects who value task performance will choose others who have effective task traits, and subjects who value social or emotional traits will choose on that basis (Eisenstadt, 1970; Gustafson, 1973; Turk, 1961). However, the conclusion of most research is that social traits are more predictive of most attraction choices (Diggins, 1974). As space crews become more heterogeneous with regard to social traits, longer interaction times will be required to overcome attraction problems or to support attraction based on task performance.

The importance of composition and interpersonal attraction

arises from research findings which suggest that groups which are compatible with respect to needs and personality characteristics are able to function more smoothly, devote less time to group maintenance, and thus achieve their goals more effectively than incompatible groups (Shaw, 1981). The USS Ben Franklin submarine study (cited in GWUMC, 1974) demonstrates the importance of social and psychological compatibility with respect to needs, values, personalities and goals. In this study, the investigators actually predicted negative interaction from pre-mission psychological profiles of the crew members. Such negative interaction often results in the failure of groups to achieve the established goals (Haythorn, cited in GWUMC, 1974). Further, the 1974 Ocean Research Vessel (RV) studies off California illustrates how a heterogeneous cultural gap between the few marine scientists ("intellects") and the RV crew ("workers") can result in value gaps, incompatibility, and crew interpersonal conflicts to the point of crew sabotage of the scientists' experiments (Bernard, Killworth & Collins, 1974).

The 1977 SMD III study and 1974 Skylab III mission also concluded that compatibility increases if the crews are homogeneous in training and status. If crews train differently, there is the perception of status distinctions and each group develops its own norms which may conflict when the entire crew forms for a mission. The Skylab (1973-1974) and Sealab (1964-1965) missions experienced incompatibility between space/underwater crews and the mission/top-side crews which was the result of differences in training and status. Bluth (1979) suggests that space mission principal investigators (PI) should

be included as team members and be present for all training and mission events in order to develop team identity. Akins (1981) suggests that NASA should insure mission controllers are accepted and respected by the crew to reduce incompatibility or inflight conflicts. In sum, several studies indicate that social, value, and group goal homogeneity is ideal for interpersonal attraction and compatibility in most cases, but heterogeneity in abilities and skills is generally best for a crew which must accomplish a complex task.

Much research supports the view that heterogeneity is important in task-oriented groups. Shaw (1981) hypothesizes that other things being equal, groups composed of members having diverse, relevant abilities perform more effectively than groups composed of members with similar abilities. He also hypothesizes that sexually heterogeneous groups are more effective because members conform more in mixed-sex groups than in same-sex groups, which results in better compatibility. Haythorn's review of group composition studies (cited in GWUMC, 1974) concludes that daily contact among people with different outlooks and professional backgrounds provides mutual stimulation which results in higher research performance. During the Skylab II mission, both the military commander and the civilian scientist felt the heterogeneous mix from the two backgrounds helped each understand both the overall mission and the value of their interdependent roles needed to attain mission objectives (Cooper, 1976). Since future space missions will be more complex in terms of specialized roles and diverse abilities, heterogeneity appears to be the most effective characteristic of crew composition.

b. Situational Factors Affecting Compatibility

In addition to basic composition, crew compatibility is also affected by the situation surrounding the interaction between crew members. The situation includes the interaction environment and the size of the crew. In general, groups which interact in isolated environments, which are dependent on each other for survival, and which are together for long periods of time, tend to be the most compatible. Under these conditions, the formation of shared values, norms, common identity, and sense of purpose is facilitated. In short, the situation provides strong motivation for the individual to be part of the group, and the group can teach the individual what group membership means without outside interference. Under these conditions, the importance of group membership is very salient and the social control exerted by the group is very strong.

The experience of groups in analogue environments underscores the importance of the interactive environment. In the 1966 Antarctic study and the 1965 Sealab II missions (cited in GWUMC, 1974), members reported that they were in a 'Total Institution' (group members lived and worked completely isolated from society for extended lengths), and shared a "common fate." Both studies concluded that the group focused on common goals (vs. individual goals) to escape the threat. Thus a primary focus on common goals and situations enhances the group's compatibility and performance.

Size is another crucial factor affecting the quality of interaction in small groups because increased size tends to limit the possibility of regular and meaningful interactions, the

development of a shared identity and sense of collective purpose, and the development of consensus about behavioral norms (Hare, 1962; Wilson, 1971). Increasing the size of a group simply increases the number of possible interactions between its members. Mathematically the possibilities are predicted by the following relationship: $y = x(x-1)/2$ where y is the number of simple two-way relationships and x is the number of people in the group (Wilson, 1971). Increased size produces increased differentiation, formal administrative coordination, and formal control, along with disproportionate increases in the potential number of social relationships (Wilson, 1971).

Most of the research on the effect of size in small groups has centered on the operation of dyads and triads. Dyads are the basic relationship unit. By themselves they tend to be special relationships, characterized by closeness, mutual dependence, high rates of tension, and emotion (Bales & Borgatta, 1955; Simmel, 1955; Strodtbeck, 1951). The introduction of a third person into the dyad relationship tends to have a stabilizing effect because members have an alternative dyad in which to participate, an additional person to provide objective feedback or mediation, and another person to break the continual deadlock experienced by only two. However, the increased options offered by odd numbers of persons pose a disadvantage to the member who is constantly on the losing side of conflict issues in which coalitions are formed to block the influence of a particular member or a group of members (Hare, 1962). Even so, the opportunity to change coalitions is an advantage in larger groups, and odd-numbered groups will be more stable than those

with even numbers.

In regard to an optimal size, there has always been different opinions. Hare (1962) suggests that, at least in terms of satisfaction in discussion groups, five may be the optimum group size. Below this size, members complain that the group is too small, face-to-face interactions are strained, and the odd/even effects are more powerful. Above the size of five, members complain that the group is too large and participation is restricted. Five is optimum because: a deadlock is not possible with an odd number, the groups tend to split into a majority of three and a minority of two so there is no individual isolated, and the group is large enough to allow members to shift roles or to withdraw rather than resolve awkward issues (Hare, 1962). In situations where the task demands group sizes larger than five, it must be remembered that the tendency for the group to split into subgroups becomes marked as the group size increases (Hare, 1962; Homans, 1953) and the formation of sub-groups will represent an informal group structure based on interpersonal choice (Klein, 1956; Roethlisberger & Dickson, 1939).

The issue of group size has been noted in the studies of small groups in analogue environments, particularly with regard to differences between dyads and triads. In the Project ARGUS Study (cited in GWUMC, 1974), for example, dyads registered significantly higher states of anxiety throughout the confinement than triads. This study concluded that a triad may be a better size than a dyad if the members are compatible, but perhaps only if senior (or respected) leadership is available. The same experiment found that triads with senior leaders registered the

lowest stress. Bluth (1982) did not study dyads vs. triads, but concludes that even-numbered groups disagree more than odd-numbered groups because polarization is more likely to occur.

In summary, these various studies indicate that when complex tasks must be accomplished, crew members that differ in abilities and skills can form a strong and effective task-oriented group. An even stronger group can be found if members are selected according to compatibility along several dimensions. Because of intersecting interests and traits, people become attracted to each other in such a group; this work group can co-function as friendship group.

These effective and productive groups do not happen by chance, however. One must get compatible people together in relatively few numbers and provide opportunities for interaction and a real sense of purpose. The difficult part of this statement centers on the phrase, "get compatible people together." Written tests and interview techniques can be used to classify people by profiles or syndromes, but these methods are fallible. A better method is to assemble a number of people for a generalized training program before some are selected out as groups or crews for mission-specific training. One criterion for selection into a specific group is the attraction demonstrated among members during the earlier training. NASA has probably used this or a similar model in the past to aid in crew selection. Unfortunately, the future emergence of the civilian or one-mission astronaut who spends a minimal time in training at NASA limits the utility of this approach. However, to the degree that compatibility is assessed by test, interview, or observed

behavior, it promises to be a very important variable for crew functioning in the space stations.

4. Task Characteristics

All groups exist to pursue some kind of purpose, either to accomplish a specific task or to provide for the group members' social-emotional needs. This section will deal primarily with groups oriented toward explicit and tangible goals; that is, groups where interactions are generally characterized by less emotion, more objectivity, and involving more restricted relationships with others, and groups which place more emphasis on technical qualifications and skills in assigned tasks (Nixon, 1979). In this approach the task is the critical factor which affects both group structure and process (Hare, 1976).

The characteristics of a task dictate the nature of the interaction required for successful completion of the task. Steiner (1972, pp 17-39) developed a basic classification of task characteristics including:

1. Additive tasks- those requiring parallel but coordinated actions by two or more persons, e.g., stuffing envelopes, pulling on a rope, etc. This task requires the maximum coordinated effort of all members.
2. Disjunctive tasks- one particular solution must be chosen or the effort of only one member can be applied, e.g., the rope pulling task if only one member can pull at a time. This task requires the best effort of the most qualified member.
3. Compensatory tasks- those requiring compromise or

averaging of abilities so that limitations of one member are cancelled out by the strengths of others, e.g., estimations of weights which are averaged for the best judgement. These tasks are nondivisible and require effort and compromise from all members.

4. Conjunctive tasks- those which require simultaneous work on a nondivisible task in which no individual can do better than the least competent person permits them to do, e.g., mountain climbing. This task requires the least competent to do his or her best and others to adjust their behavior to him or her.
5. Divisible tasks- those for which the division of the task is possible allowing performance by an individual or subset of members, e.g., a football game in which some are required to block, some to tackle, some to run the ball, etc. This task requires allocation of the task to the best qualified and coordination of all efforts.

Steiner's work (1972) illustrates the constraints placed by the task on group interaction, specifically, whether the task can be divided into parts, whether the various parts can be performed simultaneously or require a temporal order, and how the contributions of different individuals can be combined.

Although the exact tasks of a space station have not yet been specified, the task categories listed in the habitability section of this report suggest that all five of Steiner's task types will be represented. Task type will influence not only the degree of crew interaction but also will dictate the type of training

needed to accomplish the task. Thus the characteristics of the tasks themselves - derived from the 'top-down' design process - will set the stage for the development (or lack thereof) of group dynamics skills. If the majority of the space station tasks can be classified as divisible or even disjunctive, effective group processes will be of lesser importance. Conversely, a predominance of additive, compensatory, or conjunctive tasks will elevate the need for crew members to possess group dynamics skills.

Task characteristics interact with other variables to change the nature of the situation in which the group must perform (Hare, 1976; Shaw, 1976). For example, when the task is additive or disjunctive, productivity increases with group size but decreases when tasks are conjunctive. When group tasks are complex, decentralized communications are most successful while centralized networks are more efficient with relatively simple tasks. In any group, those who are more successful tend to communicate more freely and coordinate activities more closely than those in unsuccessful groups. Cooperative groups (those in which performance rewards are allocated to the group as a whole), compared with competitive groups (those in which rewards are provided to individuals), tend to have the following productivity-related characteristics: stronger individual motivation, greater division of labor, more effective communications, more friendliness between members, and greater productivity. Groups that are well organized tend to be more productive; however, any shifts in the status structure will result in more activity in the social-emotional area and a

decrease in productivity. Likewise, consensus about leadership structures and the focus of those structures on group goals tends to support goal attainment. Further, changes in the nature of the task require changes in the leadership of the group; that is, unstructured tasks require relationship-oriented rather than task-oriented leaders and crisis situations require leaders with experience rather than intellectual ability (Fiedler, 1964, 1982). In sum, task and situational characteristics operate to affect the character and quality of interactions occurring in small, task-oriented groups.

In regard to tasks, another concern is the motivating potential of the job or task itself. Hackman and Oldham (1980) identify motivating jobs/tasks as those having the following qualities: skill variety, task identity, task significance, autonomy, and feedback. Tasks without these qualities are generally described as less satisfying, boring or tedious, and result in alienation or burnout. Future space missions of longer duration have a greater potential to be less satisfying because routine, repetitive tasks reduce perceptions of skill variety and task significance. Numerous studies in analogue environments indicate subjects easily become bored in isolation if they are not fully utilized and provided tasks with motivating potential.

The motivating potential of tasks has been relatively unimportant in previous missions because the tasks have been significant and feedback has been nearly immediate. On longer missions, the routine nature of the tasks becomes an important concern. For example, on a 60-day mission what will a payload specialist do after his or her significant tasks are performed

(day 28), or if his or her tasks are aborted due to mechanical failure? Indeed, the Soviet literature (Zaitsev, 1982) reports that they are exploring the use of robots to accomplish the more routine tasks. In fact, the Soviets contend that the robots will be used for the "technician" role currently performed by the cosmonauts.

In the American literature, Akins (1981) underscores the importance of task characteristics by suggesting that some mission training should be accomplished during the flight to provide for both a change to the routine and a challenge to the crew. He also recommends that work schedules be varied and the crew be allowed some freedom in task selection so that the tasks do not become redundant. Honigfeld's review (cited in GWUMC, 1974) of confinement of groups supports this view by concluding that simple, routine tasks should be supplemented with more complex tasks to prevent boredom.

5. Environment and Facility

Facilities in space will be small due to economic considerations and payload capabilities, but close quarters is not the same as crowding. Perceptions of crowding depend on psychological variables. In other words, density is physical in nature whereas crowding is psychological and differs with individuals.

The important distinction between "density" and "crowding" was first noted by Stokols (1972, 1978) who defined density as the number of people per unit of space, a physical characteristic of the environment. Crowding, on the other hand, is a psychological or experiential characteristic of the environment

which may or may not be the same as physical density. Individuals "feel" crowded when they are forced into unwanted social contacts (overload theory), or they feel they have lost control over their own physical or social world (control theory), (Altman, 1975; Forsythe, 1983; Milgram, 1970; Saegart, 1978).

Individuals and groups tend to divide the physical space in their environment into territories -- areas of exclusive use that are generally marked and defended. This territorial division affects and is affected by social interaction. Basically, territories organize relationships between group members by: helping individuals locate one another; defining appropriate behavior and regularizing activities (e.g., sleeping, eating, working, etc.); defining what belongs to whom; confirming personal identities and status; facilitating or inhibiting interaction; and providing a source of much conflict (Altman, 1975; Durand, 1977; Edney, 1976; Forsythe, 1983).

Altman (1975, pp 112-118) classifies the division of territories by humans into three types: primary, secondary and public. Primary territories are those "owned and used exclusively by individuals or groups"; "clearly identified as theirs by others." Examples are a family's home, a dorm room, a bedroom. Secondary territories are those "places over which an individual or group has some control, ownership and regulatory power, but not the same degree as over primary territory." Examples are a table in a restaurant, a regularly used parking place, the sidewalk in front of your house. Public territories have "a temporary quality, and almost anyone has free access and occupancy rights." Examples are elevators, a bathroom stall, a

telephone booth. Crowding occurs when individuals expand their primary and secondary territories into the public territory.

There is considerable evidence which demonstrates the importance of territoriality to the interaction of groups in isolated environments (for summaries see Altman, 1973, 1977; Haythorn, 1973). In the 1964-1965 Polaris submarine voyages of 60 days with a crew of 140 men (cited in GWUMC, 1974), a pecking order was established around bunk areas and seating areas in the mess. In two 1965 Penthouse experiments by Space Sciences Laboratory (cited in GWUMC, 1974), groups of 6 and 12 men were isolated for 88 and 43 days, respectively. The investigators observed the isolated subjects staking out areas of exclusive use (near their beds) and noted that they became hostile toward trespassers. In general, some groups in isolation use territoriality dysfunctionally by strengthening territorial barriers and keeping to themselves, while other groups use territoriality to their advantage by relaxing barriers, negotiating the use of public areas, and interacting cooperatively to get through their ordeal (Altman, 1973).

While territoriality is a division of the physical environment, personal space is a division of the psychological environment, that is, the social distance between persons. Personal space is like an invisible bubble that surrounds the individual and provides a boundary limiting physical contact with others.

Personal space, like territories, is actively maintained and defended, but varies with the situation or the individual. Several studies suggest highly cohesive groups can tolerate

crowding or density better than noncohesive groups (Evans & Howard, 1973). Groups of friends occupy less space than groups of strangers (Edney & Grundmann, 1979). Evidence also indicates personal space expands when people are stressed (Dosey & Misels, 1969). Parker's review (cited in GWUMC, 1974) of habitability concludes that when provisions for personal needs (environment and facility characteristics) fail to meet the crew's expected standards, morale declines and performance is degraded. Herzberg's Motivation-Hygiene theory (1976) predicts this decline, warning that deficient hygiene needs (the environment of the job) must be fixed before workers can be motivated. Specific guidance is provided by Fraser (cited in GWUMC, 1974) who concludes that for confinement periods of 30-60 days, about 150 cubic feet of free volume per person is required to reduce the sense of crowding. At the same time, he suggests that weightlessness may improve tolerance of confinement by allowing use of the entire volume of a cubicle (both the floor and ceiling).

Violations of personal space are major sources of individual stress. Experiments with crowding report outcomes including: worsened task performance, heightened interpersonal conflicts, anxiety, and emotionality (Altman & Haythorn, 1967). To reduce this stress, the individual tends to withdraw from the group and to limit social contacts. Typically, individuals in isolated environments cite "lack of privacy" or crowding as a major complaint (Antarctic Deep Freeze, 1955-1968; Fallout Shelter experimental studies, 1962-1968; Fallout Tests, 1959-1960; USS Ben Franklin, 1963; Sealabs I, II, III, 1964-1965; Tektite,

1969-1970; Skylabs I, II, III, 1973-1974; all cited in GWUMC, 1974). As isolation continues, subjects seek more privacy. Altman and Haythorn (1967) describe this behavior as the "cocooning" effect -- subjects withdraw from the group, become loners, and remain so until near the end of isolation. Recognizing that density, crowding, territoriality, and personal space are important for group cohesiveness and performance, facilities for space station crews should be designed to alleviate these problems, given the constraints of dense or close quarters. Akins (1981) recommends that if physical space permits, living and work areas should be distinct to allow for some privacy.

Several factors are related to the impact of close quarters. First, performance of groups with low interactive qualities suffers when they experience situations of high density (McCallum, Rusbult, Hong, Walden & Schopler, 1979; Sunderstrom, 1975). A second factor is the size of the group (Wicker, 1979; Wicker, Kermeyer, Hanson & Alexander, 1976). In general, overstaffed or understaffed groups perform inadequately. Finally, the gender of group members seems to affect the relationship between density and performance. The majority of studies suggest men react negatively to crowding while women sometimes enjoy and work better in crowded situations (Epstein & Karlin, 1975; Paulas, Annis, Seta, Schkade & Matthews, 1976; Ross, Layton, Erickson & Schopler, 1973). Further, some studies suggest men become more competitive, hostile and withdrawn in a crowding situation (Freedman, 1975; Ross et al., 1973). Epstein and Karlin (1975) conclude that reaction to crowding may be

governed by different sex norms about sharing distress: women perceive that distress should be shared, whereas men perceive that distresses should be concealed.

The perception of crowding can be reduced by NASA using the following strategies. One solution to unavoidable crowding may be varying work schedules so that there are fewer people in a given area. For example, two of five crewmen could be asleep, and the three working crewmen could be in different parts of the spaceship/spacestation performing tasks. However, Eberhard (cited in GWUMC, 1974) concludes that to prevent withdrawal and cocooning, mission time lines should be scheduled to insure that the maximum amount of social interaction is possible during off-duty times, for instance, during meals. By isolating crewmen doing work functions and gathering them for social interaction, the sense of crowding will be reduced and the effects of isolation are minimized. Levine (cited in GWUMC, 1974) suggests a second alternative -- selection by psychiatric methods -- to eliminate crew members who do not react well to isolation and crowding. He also recommends a high level of training as a group to experience the problems inherent in a crowded working environment.

6. Selection and Training

As previously discussed, most work group members are selected for technical qualifications and trained to improve their technical skills. However, selection and training must be done in the context of three key factors: the task, the organization, and the environment. If group dynamics affect group performance, then selection should consider social as well as technical

skills, and training should be designed to develop interaction skills as well as technical skills of the group as a whole.

Numerous isolation studies assert that the secondary consideration for selection should be social factors. The Antarctic Deep Freeze, Alaskan Air Command, USS Ben Franklin, Project ARGUS, Soviet Soyuz and Salyut missions all recognized the need for compatible, individual psychological traits, and recommended pre-mission psychological screening to prevent group interpersonal conflict (cited in GWUMC, 1974). In fact, these studies assert that psychological variables may be more important than physiological variables in the selection of individual crew members for long-term space missions. In support of this contention, negative crew interaction has been predicted by pre-mission psychological testing in both the USS Ben Franklin voyages and the Sealab missions. Thus, it seems reasonable to assume that pre-mission psychological screening may increase the probability of positive interaction.

Akins (1981) suggests that selection should be based on the group rather than the individual because the group is the key to mission success. He suggests NASA select effective groups, not just effective, technically skilled individuals.

Groups are more than the sum of the individual members. Therefore, selection of the group as a whole may be the best selection process. While an individual may be outstanding in a particular field, he or she may not be an effective group member (perhaps an introvert). Astronauts, for example, tend to be independent, concrete specialists who are not necessarily sensitive in the social sphere. In fact, they may be emotionally

aloof, and these qualities may be detrimental in longer missions (Akins, 1981). In the shorter missions of the past, NASA has selected outstanding individuals. However, if a group's performance is the key to success for long-term flights, the socially-demanding conditions of isolation require the selection of socially-oriented group members who are better equipped to accomplish group social-maintenance functions. Therefore, whole crews, not just individuals, should be selected for longer missions to insure compatibility and social orientation as well as technical expertise (Akins, 1981). Given the large selection pool of individuals who are physiologically and technically qualified, Akins (1981) argues that social compatibility may be the deciding factor for selection "into" a crew designated to accomplish a particular mission. Selecting crews in this manner should enhance mission effectiveness.

The experience of crews in analogue environments highlights the importance of social compatibility as a selection criterion. The Antarctic Deep Freeze studies (1955-1968) found that groups isolated in a hostile environment were most threatened by emotional instability and social incompatibility, and suggests that members should be screened and selected based on social compatibility. In support, Shaw (1981) hypothesized that individuals who are positively oriented towards people enhance social interaction, cohesiveness and morale in groups; whereas people who are positively oriented toward things inhibit interaction, cohesiveness and morale. Bluth (1982) concludes that two to three-week missions have not been characterized by social problems, but longer missions generate a higher degree of

performance degradation traceable to human factors. Therefore, psychological factors must be considered when planning longer space missions.

After selection, training becomes important for at least three reasons: 1) improvement of technical expertise; 2) development of group dynamic skills; and 3) testing the interaction of the personal characteristics of individual members. One of the clearest findings in the small group dynamics literature is that group productivity improves with training (Hare, 1976). Individual training improves technical skills and group training improves coordination of tasks. Investigators in the Martin Marietta spaceflight simulation support this need for training by stating that the more training and preparation undertaken prior to the flight, the lower the probability of inflight difficulties (cited in GWUMC, 1974). Essentially this is the current emphasis of NASA crew training.

In addition to technical skills, training should develop group dynamics skills to improve cohesiveness and group performance over the long term. Doing so reduces the frequency and severity of intercrew difficulties (Jackson, Wamsley, Bonura, & Seeman cited in GWUMC, 1974); makes the crew members aware of other's feelings (Dunlap cited in GWUMC, 1974); develops team identity (Bluth, 1982); and fosters group unity (Angiboust, cited in GWUMC, 1974). Even the Soviets in the Salyut 6 mission trained crews in human relation skills by role playing in conflict and stressful situations (Zaitsev, 1982). When crews are trained separately, a rift can develop between the astronauts and the mission and payload specialists. In one instance (SMD

III), these subgroups developed their own status and prestige norms which were perceived as an "elite" treatment of the astronauts. To prevent this type of rift, homogeneity in training and status is often recommended. An implicit assumption of group training is that an entire crew be rotated as a unit if possible, thereby reducing the sense of isolation of single newcomers who did not train with the original group (Bluth, 1982).

Simultaneously with the acquisition of technical and group dynamics skills, training serves as a dynamic test of individual member compatibility. New tasks and new situations inherent in training are especially suited for this purpose. Given enough time, the incompatible characteristics of the group members will be identified and conflict will occur. When it does, the group can strengthen its group dynamics skills and resolve the conflict or the disruptive members can be selected out of the group. Either solution increases the probability of mission success.

Effects of Cohesion and Performance

The raison d'etre for task groups is performance of a task or tangible goal attainment. Therefore, the proper design of task groups must focus on factors affecting productivity and how they operate.

Productivity or performance in groups is a complicated issue which has puzzled behavioral scientists for many years. It is well known that the presence of others in some cases enhances an individual's performance through a phenomenon known as social facilitation (Allport, 1920; Dashiell, 1930; Travis, 1925). That is, the mere presence of others raises the performer's arousal

level by touching off a basic alertness response (Zajonc, 1965, 1980) or by generating apprehension about being evaluated (Cottrell, 1972; Henchy & Glass, 1968; Weiss & Miller, 1971). Although the individual is motivated to perform better, performance does not always follow, in part because concern over the evaluation of others distracts attention which should be allocated to the task (Sanders, 1981; Sanders & Baron, 1975; Sanders, Baron & Moore, 1978) and, in part, because the response facilitated may not be appropriate for the task at hand (Geen, 1980; Geen & Gange, 1977; Zajonc, 1980).

In short, performance in groups is not simply the sum of the performance capabilities of all the members. It can be more or less depending on the characteristics of the members, the task at hand, the situation under which the task must be accomplished, the structure of the group, and the nature of the interactions among group members (Davis, 1969; Hackman & Morris, 1975; Laughlin, 1980; McGrath, 1964; Shaw, 1981; Tubbs, 1978). Those who study productivity (Kelly & Thibaut, 1969; Latané, Williams & Harkings, 1979; Petty, Harkins & Williams, 1980; Shaw, 1981; Steiner, 1972, 1975; Williams, Harkins & Latané, 1981) describe group performance as follows:

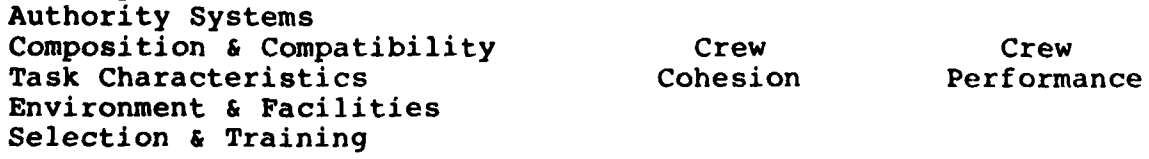
Actual Productivity = Potential Productivity - Losses due to Faulty Process + Gains from Group Process

1. Cohesion

The major outcome variable used to assess the group "process" described above is group cohesion. Cohesion can be defined as the total field of forces which act on members to remain in the group (Festinger, Schachter & Back, 1950). Used as a summary

term, several conceptual meanings have been attached to cohesiveness including: the attraction of a group for its members, the coordination of group member efforts, and the motivation of members to do a task with zeal and efficiency (Golembiewski, 1962). Cohesion is closely linked with commitment to group goals, identity with group members, satisfaction with the group, mutual support provided by other group members, and the absence of group conflict. For many researchers, cohesiveness is the essential theoretical variable for small groups. Cohesion is critical to understanding small group behavior because it is the major outcome of both the "top-down" and "bottom-up" design process.

Essentially, cohesion operates as an intervening variable. Affected by all the design considerations already discussed, it serves to moderate the relationship between these factors and actual group performance (Dayhaw & McInnis, 1970; Deutsch, 1959; Good & Nelson, 1971, 1973; Heslin & Dunphy, 1964; Samuels & O'Rourke, 1969; Shaw & Shaw, 1962). Cohesion, then, is the result of many design factors and a major determinent of performance as well. The development of cohesion in groups is a complicated matter which is best understood by exploring the effect of each design characteristic individually. The following figure depicts this relationship:



Role specification contributes to cohesion because it defines

or structures the interaction between group members. Role specification promotes cohesion to the degree that it produces predictable and stable patterns of interaction. Generally, cohesion is enhanced by similar roles, interdependent roles, and roles focused on the same goal. Similar roles, for example, provide individuals an opportunity for shared experiences, common values and shared outlooks (Durkheim, 1964; Homans, 1974). Different roles which are directed toward the same goal foster cooperative relationships as long as the individual efforts are interdependent, that is, combined efforts are required to achieve the desired goals (Durkheim, 1964; Goffman, 1961). Conversely, role specification may impede cohesion if the roles are specified as independent or if they are directed toward different goals. In this case, cohesion will be reduced because the roles are divisive and the individual efforts as well as experiences are independent.

In addition to the nature of specification, the degree of specification is also important. For example, underspecification will require the group to expend more effort organizing and coordinating its effort. Overspecification, on the other hand, may limit performance latitude and reduce the importance of jobs, thus creating alienation from individual tasks and the group itself.

These important relationships between role specification and cohesion are highlighted by the Antarctic Deep Freeze studies (1955-1968) which found the greatest number of positive interpersonal relationships occurring between work partners and by the Sealab II experience in which group cohesion was fostered

by the crew members' perceptions of sharing a "common fate." During the Skylab flights, overspecification of roles generated alienation among some crew members. For six weeks the crew carefully followed the daily schedule which detailed every task. However, by the sixth week they became alienated and announced to Mission Control they were "taking the day off" (Cooper, 1976). After some discussion which aired the crew's frustrations, performance improved. Task specification, then, promotes cohesion by focusing individual efforts, providing opportunities for shared experiences, and creating mutual interdependence, but overspecification can be dysfunctional.

Authority structures, the second design consideration, also focuses the group's efforts toward mission concerns. These structures place decision-making responsibility with those best qualified to decide and inhibit individual and sub-group efforts to gain influence over others in particular situations (Klein & Christiansen, 1969). In short, clearly established lines of authority legitimize the influence of those in decision-making positions and reduce the need for conflict and negotiation about critical aspects of the mission (Hare, 1976).

Generally, the research suggests that groups which are well organized and have clear lines of authority are usually more productive because they spend significantly less time on social-emotional activities (Darley, Gross & Martin, 1952; French, 1941). Conversely, groups in which lines of authority are not clearly established (members are moving from one position to another, or when there is a discrepancy in the criteria for establishing status in the group) spend considerable effort to

re-establish the authority structure or resolve the differences with a consequent decrease in productivity (Adams, 1953; Bales & Slater, 1955; Bales & Slater, 1957; Heinicke & Bales, 1953; Shepard & Weschler, 1955; Wheeler, 1957). In addition to redirecting group efforts, the absence of clear lines of authority may also fragment the group into "cliques" which not only allow individuals to withdraw from the larger group, but also offer the possibility of "illegitimate" control through disruptive collective action with other dissident individuals (Burns, 1955). In general, lines of authority which are supported by the formal structure (established on the basis of rank or recognized expertise) will go unchallenged (Hare, Borgatta & Bales, 1955). Thus, clearly defined authority structures are critical to cohesion because they focus group efforts and prevent fragmentation.

The relationship of the third design consideration, group composition, to cohesion generally depends on the desired outcome of group interaction. If the goal of the group is mutually satisfying relationships, as with primary groups, then cohesion is greatest when the composition is homogeneous. However, if the group goal is task accomplishment, the greatest probability for success may lie with heterogeneous members. Since group activities usually involve efforts in both areas, i.e., task accomplishment when tasks must be done and group maintenance otherwise, the major composition factor affecting cohesion may be the compatibility of the group rather than its heterogeneity or homogeneity.

Studies of interpersonal attraction in small groups suggest

that people must be or perceive themselves to be similar to others in certain salient respects for them to initiate or continue interaction which will develop into stable patterns of relationships (Hare, 1976; Nixon, 1979; Philp, 1940). In fact, the perception of similarity in beliefs and interests may be more important than differences in race or other social characteristics (Stein, Hardyck & Smith, 1965). Those who study clique formation in groups support the importance of homogeneity to cohesion by suggesting the splitting of a group into cliques is a function of increased heterogeneity of the group members. That is, heterogeneous composition undermines group integration not only by disrupting communication, but by promoting the formation of sub-groups which emphasize the similarity of some group members and their differences with others (Carlson, 1960; Davis, 1963; Nixon, 1979; Stogdill, 1959).

Homogeneity of group members, then, is an important and well substantiated factor related to the cohesion of group members (Berelson & Steiner, 1964; Shaw, 1981). It is a factor that can be easily controlled by selecting individuals from common backgrounds (similar socialization) and subjecting them to long periods of similar training (additional socialization). Doing so almost always produces some degree of cohesion based on common needs, values, goals and attitudes (Terborg, Castore, & DeNinno, 1976).

While similarity is an important precondition for cohesion, some researchers suggest compatible, but different characteristics may be more important in groups concerned with productivity (Shaw, 1981). For example, experiments with

compatible groups show that groups with a high group mean on a particular personality trait tend to behave according to that trait even if the task requires different behavior or greater variance in behaviors. In such groups, tasks which call for variability in behavior tend to generate either lower productivity or conflict within the group (Hare, 1976). It seems some degree of perceived similarity is important so that group effort is not diverted to the maintenance of social-emotional relationships, but group tasks which require a variety of skills and knowledges are more likely to be accomplished successfully by heterogeneous groups (Hoffman, 1959; Hoffman & Maier, 1961). The critical requirement here is not homogeneity of member characteristics, but their compatibility; and compatibility appears to be a function of three factors: reciprocality of relationships, opportunity to interact over a period of time, and similarity of attitudes (Crosbie, 1975).

Task characteristics, facility design, and training, the final three design considerations, are factors related to cohesion in that they constitute the environment in which the group operates. As such, they affect the dynamics of the group. For example, group dynamics research has shown that the nature of the task and reward structures have profound effects on in-group identities and group productivity. Cooperative tasks, those requiring the resources of the entire group, tend to foster strong bonds with others working toward the same goal while competitive tasks, those in which one person or group wins at the cost of the other, tend to foster resentment, conflict, and aggression (Sherif, 1961). Similarly, reward structures which

are based on group effort foster cohesion and those based on individual effort do not. The combination of task and reward structures affect productivity in that the greatest loss of productivity occurs when tasks are interdependent and rewards are individual (Miller & Hamblin, 1963).

The situation can be more complicated when individuals operate in coacting groups (groups which are interdependent) and rewards are based on individual effort within the winning group. In this case, the individuals must cooperate with others in their own group to out perform the other group and then they must compete with others within the group to maximize personal rewards. The result is some loss of group cohesion and some reduction in productivity (Okun & DiVesta, 1975).

Work facilities, work schedules, and previous training are important determinants of group dynamics because they control the opportunities for interaction among group members. Different geographical locations and times create different groups with different patterns of interaction, different identities, and different norms (Lipset, Trow & Coleman, 1956; Stone, 1970). Homans (1950) summarizes the effect as a problem of "differential interaction." Basic differences in the circumstances of work, e.g., task, time, location, and previous group experience, create increasingly differentiated subgroups and affect cohesion within the larger group.

Based upon the above discussion, the following guidelines should apply to developing cohesion in space station crews. First, roles must be specified but not overspecified. Second, lines of authority must be clearly established but changed

according to the task. Third, crew members must be selected for and trained for compatibility. Finally, tasks, facility utilization, schedules, and training should allow for maximum interaction and cooperative activities.

2. Performance

The relationship between cohesion and performance is complicated. While it is generally thought that cohesion leads to greater productivity, that is not always the case. Some researchers suggest that cohesion may be the most powerful predictor of performance (Goodacre, 1951; Hare, 1976; Shirom, 1976). Clearly, cohesive groups are more satisfied. They tend to be friendlier, more cooperative, and more inclined toward behavior enhancing group integration than groups low in cohesion (Back, 1951; French, 1941; Lott & Lott, 1961; Shaw & Shaw, 1962). They are more satisfied with products produced by the group (Shaw, 1976). In general, they work harder and produce more since they spend less time on group-maintenance issues, and exert stronger pressures for conformity on their members (Shaw, 1981). Effort directed toward the group's goals and productivity is less likely to be lost to faulty group processes such as poor coordination or "social loafing" (Steiner, 1972, 1976).

While cohesive groups are more efficient in their group processes, the outcome of these processes is not always performance. For example, cohesive groups tend to reach decisions quickly and easily, but they may be the wrong decision as in the case of "groupthink" (Janis, 1972). Further, they are subject to the "risky shift" phenomenon in which individuals who make conservative decisions when alone, shift to more risky

positions during the group decision process (Stoner, 1968). Sometimes cohesive groups spend too much time in social-emotional activity and forget to get the task done (Bos, 1937; Horsfall & Arensberg, 1949; Nixon, 1979; Philp, 1940). Perhaps the major risk of cohesive groups, however, is the possibility that they may adopt and enforce norms which are contrary to the larger organization (Lott & Lott, 1965; Schachter, Ellerton, McBride & Gregory, 1951; Warwick, 1964). In all of these situations, cohesion helps the group operate more effectively, but toward an outcome which is dysfunctional in respect to the task established by those outside the group.

Past crews have been cohesive and their performance high as a result. Possbile dysfunctional outcomes have been reduced by ground crew involvement in critical decisions and by relatively short mission durations which leave little time for deviant behavior. Nevertheless, some dysfunctional outcomes directly attributable to cohesion have been noted - specifically the "day off" in space incident. The frequency of dysfunctional behavior related to cohesion is higher in analogue experiences and is likely to increase in space missions as flight duration increases. Still, cohesion is generally a positive attribute which enhances mission success. As such, it should be a major goal for the design of the human sub-system.

Summary and Conclusions

The real change to current NASA mission design procedures is the requirement to give greater consideration to "bottom-up" processes, that is, how groups respecify their roles, build compatibility, promote cohesion, and improve productivity. Doing

so fosters informal "bottom-up" support of the formal "top-down" design.

Perhaps the easiest and most effective way to influence the "bottom-up" development process in the human sub-system is through training. Rather than individual, short term training directed toward the acquisition of technical skills, long term training of the entire crew may be more effective. During this training, the group dynamics processes can be carefully monitored and adjustments made for dysfunctional developments. Group training provides an opportunity to test and validate the selection of individual members, the formal specification of roles and task requirements, and the design of the facility. Over time, shortcomings in the formal design will be revealed and redesign can be initiated in a timely manner. Also over time, problems in crew compatibility will surface and threats to crew cohesion can be identified before performance is adversely impacted. Long term crew training not only allows monitoring of the group process, but it affords an opportunity to train the crew in group dynamics skills so that the crew, itself, can correct faulty "bottom-up" group processes. Long term training of the crew, then, allows opportunities to both monitor and facilitate the informal processes of the crew to insure maximum performance and mission success.

Proper consideration of group dynamics principles in the design of future long duration space missions is no longer a luxury. It is imperative for success. In the past, these principles may have been overlooked, but the special nature of early flights precluded major dysfunctional outcomes. The early

flights were relatively short and filled with exciting tasks. The crews were small in number and from similar backgrounds. These factors, in effect, controlled many potential group dynamics problems. Even so, dysfunctional outcomes were noted. In the future, longer and more routine missions as well as larger and more diverse crews will not allow neglect of group dynamics. In fact, consideration of these issues may well mean the difference between crews who exceed performance expectations and those who accomplish less than what is required.

Both the theoretical research and actual experiences of groups in isolation underscore the importance of group dynamics processes to the success of future space missions. Flight crews are more than just the sum of their individual technical skills. They are a system or set of interacting units each of which is *constrained by, conditioned by, or dependent* on the other units. The human sub-system, therefore, is dynamic and constantly changing through interaction. In fact, it has the capability to reprogram itself; to set new goals and to establish new modes of operation. This reprogramming is continual and the initial design of the human sub-system only sets the structure within which the interaction process operates. While the structure may limit the process, it does not determine it. Therefore, the process becomes the critical factor affecting system operation. When the interaction process is effective, the output of this system can be greater than the sum of the capabilities of its separate units. When the interaction process is faulty, the output may be much less. Since the interaction process of this system operates according to the principles of group dynamics,

application of these principles in the design of human sub-systems in space is the only way to insure effective operation.

Allowance for group dynamics issues in the formal "top-down" design process currently used by NASA merely requires consideration be given to how task and role specification, authority structures, and facility design factors promote or impede the group process. Where possible, task specification should facilitate interaction, that is, it should require mutual support and cooperation. Authority structures should be well established but realistic in regard to changing mission requirements. Facilities should be designed to promote crew interaction without "crowding" the individuals, and selection should consider compatibility as well as technical expertise. All these considerations are intercorrelated and can be focused to solve particular design problems. For example, crowding in the facility can be reduced by selecting compatible individuals to work together while others rest, and specifying lines of authority which are accepted by all.

The issues raised in this document are not design requirements; they are design considerations. They highlight the important relationship between structure and process in the human sub-system. They explain how the "top-down" formal design is changed by the "bottom-up" redesign process. Consideration of these issues will pay large dividends in terms of system performance, and neglect of these issues will incur costs. Actual changes to NASA policies and current practices may be minimal but nevertheless critical.

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